



AP Physics 1: Master Companion

Every equation, when to use it, and the trap to avoid

TikTok: @physicswizardtutoring

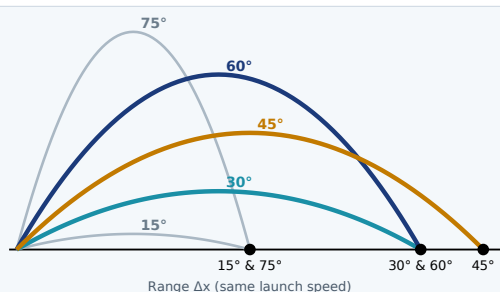
Unit 1: Kinematics

Exam weight: 10-15%

Slope of x-t is velocity. Slope of v-t is acceleration. Area under v-t is displacement. Area under a-t is change in velocity.

Equation	Missing Variable	Best Used When
The 4 Horsemen of Kinematics (constant acceleration)		
① (a) $\Delta x = v_i t + \frac{1}{2}at^2$	v_f	You need distance and the final velocity is unknown
(b) $\Delta x = v_f t - \frac{1}{2}at^2$	v_i	You need distance and the initial velocity is unknown
② $v_f = v_i + at$	Δx	You know the time and want a velocity
③ $v_f^2 = v_i^2 + 2a\Delta x$	t	Time isn't given or asked for
④ $\Delta x = \frac{1}{2}(v_i + v_f)t$	a	You know both velocities and the time, but not the acceleration
If $a = 0$: $\Delta x = v_i t$	$a (= 0)$	No acceleration (constant velocity): all four horsemen reduce to this
$v_{avg} = \Delta x / \Delta t$, $a = \Delta v / \Delta t$	-	Basic rate problems and reading graphs
Projectiles: $a_x = 0$, $a_y = -g$	-	Anything launched or dropped; solve x and y separately
$\Delta x = v_i^2 \sin(2\theta) / g$	t	Range of a symmetric projectile, given speed and launch angle
$h_{max} = v_i^2 \sin^2\theta / (2g)$	t	Maximum height of a projectile launched from ground level, given speed and launch angle

Traps: acceleration is NOT zero at the peak of a throw ($a = 9.8 \text{ m/s}^2$ down). Constant speed doesn't mean zero acceleration if direction is changing. These equations need constant acceleration.

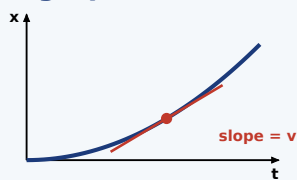


Launch Angle vs. Range

- **30° and 60°** land at the same spot. Any two angles that add up to 90° do (15° and 75° too).
- **45° goes the farthest:** $\Delta x = v_i^2 / g$.
- The steeper angle (60°) climbs higher and stays in the air longer.

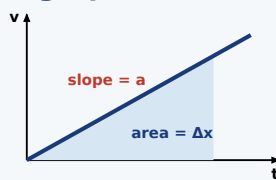
Reading motion graphs (constant acceleration)

x-t graph



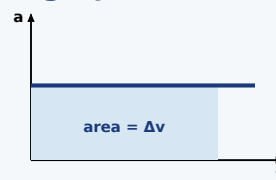
Curved when $a \neq 0$. Slope at a point = velocity there.

v-t graph



Straight when a is constant. Slope = a , area = displacement.

a-t graph



Flat when a is constant. Area = change in velocity.

Unit 2: Force, Translational Dynamics, and Circular Motion

Exam weight: 18–23%

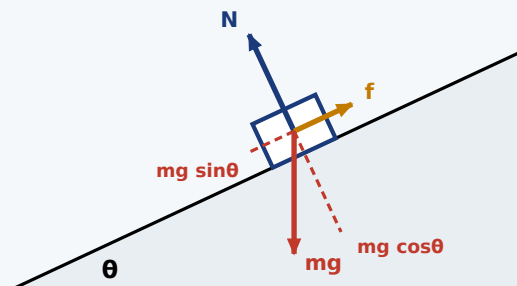
N1 inertia. N2 $\Sigma F = ma$. N3 action–reaction pairs are equal and opposite, on different objects.

Equation	Best Used When
$\Sigma F = ma$	Any force-and-motion problem; draw a free-body diagram first
$F_g = mg$	Weight near Earth's surface
$F_g = Gm_1m_2/r^2$, $g = GM/r^2$	Orbits and gravity far from the surface; r is center to center
$f_k = \mu_k F_N$, $f_s \leq \mu_s F_N$	Sliding or about-to-slide objects
$F_s = -kx$	Finding spring force from stretch or compression
$a_c = v^2/r$, $\Sigma F_c = mv^2/r$	Circular motion; net force points to the center
$v = \sqrt{rg \tan \theta}$	Banked curve: speed at which the normal force alone supplies the centripetal force (θ = bank angle, r = radius). Faster needs friction down the bank; slower needs it up
$v_{\min} = \sqrt{gR}$	Minimum speed at the top of a vertical loop of radius R to stay on the track ($N = 0$ at the top)
$v_{\text{orb}} = \sqrt{GM/r}$	Speed of a satellite or planet in a circular orbit; M is the central mass, r is center to center
$T^2 = (4\pi^2/GM) r^3$, so $T^2 \propto r^3$	Kepler's 3rd law: period of an orbit from its radius (r is center to center); for two orbits around the same mass, $T_1^2/T_2^2 = r_1^3/r_2^3$
$F_{g\parallel} = mg \sin \theta$	Incline: acceleration down the ramp
$F_{g\perp} = mg \cos \theta$	Incline: finding the normal force
$a = (m_2 - m_1)g / (m_1 + m_2)$	Two masses over a pulley (m_2 is heavier)

Traps: F_N is NOT always mg . It changes with pulling angles, vertical acceleration, and incline. Action–reaction forces never cancel because they act on different bodies. “Centripetal force” is the net of real forces, not a new force.

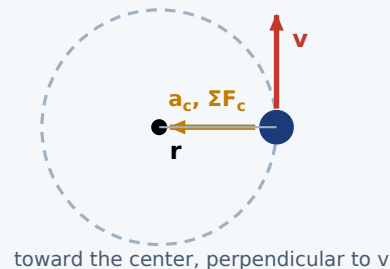
Two free-body pictures to know

Block sliding down an incline



Split mg into components: $mg \sin \theta$ along the slope (drives the motion), $mg \cos \theta$ into the slope (so $N = mg \cos \theta$). Friction points up the slope, opposite the sliding.

Circular motion



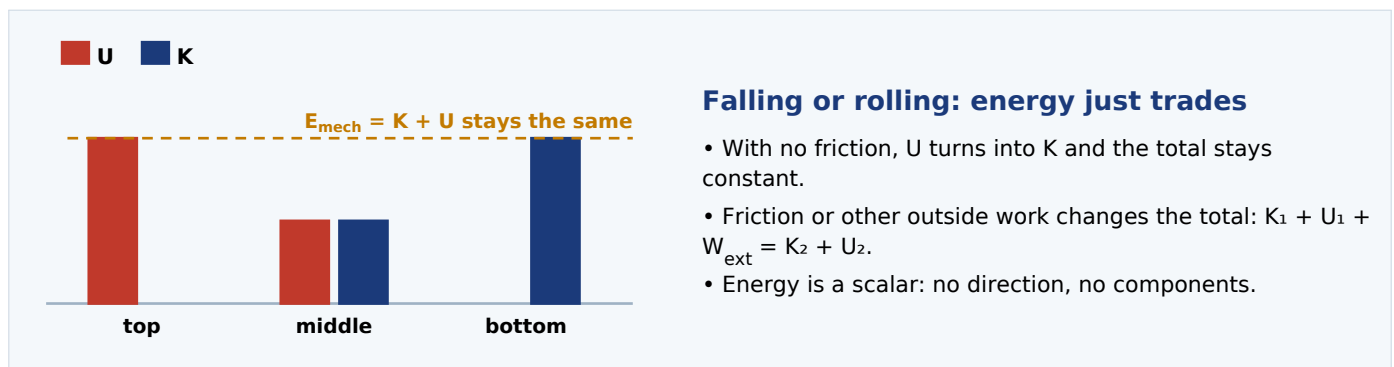
Net force and acceleration point to the center: $\Sigma F_c = mv^2/r$. The velocity is tangent. “Centripetal force” is the label for the net of real forces.

Unit 3: Work, Energy, and Power

Exam weight: 18–23%

Equation	Best Used When
$W = F\Delta x \cos\theta$	A force acts over a distance; θ is the angle to the motion
$K = \frac{1}{2}mv^2$, $\Delta K = W_{\text{net}}$	Speed changes and you know the work done (or the reverse)
$W_{\text{fric}} = -\mu_k F_N \Delta x$	Work by kinetic friction over a sliding distance Δx ; negative since it opposes motion
$\Delta U_g = mg\Delta y$	Height changes and Earth is in the system
$U_g = -(Gm_1m_2) / r$	Gravitational potential energy of two masses; r is center to center, $U = 0$ at infinity
$v_{\text{esc}} = \sqrt{2GM/R}$	Minimum launch speed to escape a planet's gravity; R is the distance from its center
$K = (Gm_1m_2) / (2R)$	Kinetic energy of a satellite (m_1) in a circular orbit around a planet (m_2)
$E_{\text{mech}} = -(Gm_1m_2) / (2R)$	Total mechanical energy ($K + U$) of a satellite in a circular orbit; negative means bound
$U_s = \frac{1}{2}kx^2$	Springs storing or releasing energy
$E_{\text{mech}} = K + U$	Total mechanical energy of a system: kinetic plus potential
$K_1 + U_1 + W_{\text{ext}} = K_2 + U_2$	Comparing before and after; friction is negative W_{ext}
$P = \Delta W / \Delta t = Fv \cos\theta$	Rate of energy transfer, or a force moving at speed v

Traps: if Earth is NOT in your system, you can't use U_g . Treat gravity as an external force doing work instead. Work by a force perpendicular to motion is zero.



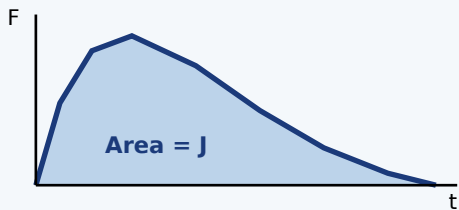
Unit 4: Linear Momentum

Exam weight: 10-15%

Area under an F-t graph is impulse.

Equation	Best Used When
$p = mv$	Finding the momentum of one object
$J = F\Delta t = \Delta p$	Short-time forces: impacts, bounces, F-t graphs
$\Sigma p_{\text{before}} = \Sigma p_{\text{after}}$	Collisions and explosions with no net external force
$x_{\text{cm}} = \Sigma mx / \Sigma m$	Finding where a system of masses balances
$v_{\text{cm}} = \Sigma p / \Sigma m$	Velocity of the center of mass; constant with no net external force
Elastic: $\Sigma K_{\text{before}} = \Sigma K_{\text{after}}$	Bouncing collisions with no energy loss
$v_{1i} - v_{2i} = -(v_{1f} - v_{2f})$	Elastic collisions: relative velocity reverses
Inelastic: K is lost	Collisions that lose energy to heat or deformation
Perfectly inelastic: $m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$	Objects stick together after impact

Traps: momentum is a vector, so set a sign convention first. In bounces and explosions, a direction flip turns subtraction into addition and changes the impulse.

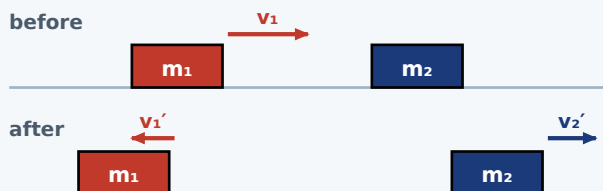


Impulse from an F-t graph

- Area under the F-t graph = impulse (**J**), and $J = \Delta p$.
- Constant force: area = $F\Delta t$. Area below the axis counts as negative.

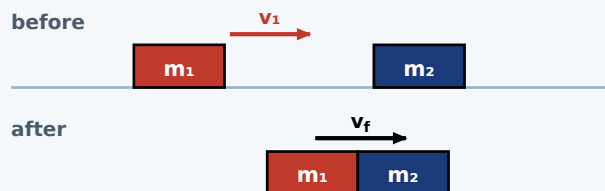
Collision types

Elastic: bounce apart



Momentum **and** kinetic energy conserved. Relative velocity reverses: $v_{1i} - v_{2i} = -(v_{1f} - v_{2f})$.

Perfectly inelastic: stick together



Momentum conserved, kinetic energy **lost** (the most possible): $m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$.

Unit 5: Torque and Rotational Dynamics

Exam weight: 10–15%

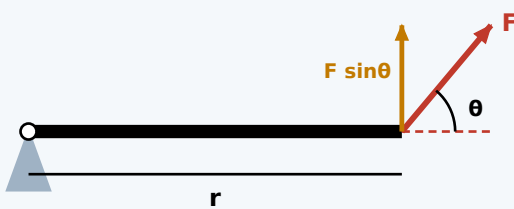
Equation	Missing Variable	Best Used When
The 4 Horsemen of Rotational Kinematics (constant angular acceleration)		
① (a) $\Delta\theta = \omega_i t + \frac{1}{2}\alpha t^2$	ω_f	You need the angle turned and the final angular velocity is unknown
(b) $\Delta\theta = \omega_f t - \frac{1}{2}\alpha t^2$	ω_i	You need the angle turned and the initial angular velocity is unknown
② $\omega_f = \omega_i + \alpha t$	$\Delta\theta$	You know the time and want an angular velocity
③ $\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta$	t	Time isn't given or asked for
④ $\Delta\theta = \frac{1}{2}(\omega_i + \omega_f)t$	α	You know both angular velocities and the time, but not α
If $\alpha = 0$: $\Delta\theta = \omega_i t$	$\alpha (= 0)$	Constant spin rate: all four horsemen reduce to this
$\omega = \Delta\theta/\Delta t$, $\alpha = \Delta\omega/\Delta t$	-	Basic spin-rate problems
$v = r\omega$, $a_t = r\alpha$, $a_c = \omega^2 r$	-	Linking a point on a spinning object to its linear motion
$\tau = rF \sin\theta$	-	Finding the twist from a force applied away from the pivot
$\Sigma\tau = I\alpha$	-	Speeding up or slowing the spin of a rigid object
$I = \Sigma mr^2$	-	Rotational inertia of point masses
$\Sigma F = 0$ and $\Sigma\tau = 0$	-	Balanced systems (beams, ladders, seesaws); choose the pivot that removes unknowns
$W = \tau\Delta\theta$	-	Work done by a torque turning an object through an angle $\Delta\theta$ (in radians)
$I' = I_{cm} + Md^2$	-	Rotational inertia about an axis a distance d from a parallel axis through the center of mass

Translational	Rotational	Bridge
Displacement x	Angular position θ	$x = \theta r$
Velocity v	Angular velocity ω	$v = \omega r$
Mass m	Rotational inertia I	$I = \Sigma mr^2$ (varies by shape)

Traps: equal forces don't mean equal torques. Pushing near the hinge gives far less torque than pushing at the edge. Torque uses the perpendicular distance from the pivot to the line of action ($r \sin\theta$). To shift axes, start from the center-of-mass value; M is the total mass and d is the distance between the two parallel axes.

Torque and balance

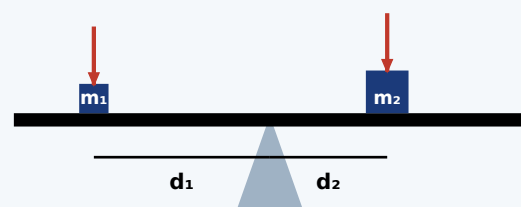
Torque from an angled force



$$\tau = rF \sin\theta \text{ (}\theta \text{ is the angle between } r \text{ and } F\text{)}$$

Only the part of F perpendicular to r twists: $\tau = rF \sin\theta$. Push at the end of the rod, at right angles, for the biggest torque.

Balancing a beam



$$\text{balanced: } m_1 d_1 = m_2 d_2 \text{ (here } m_2 \text{ is the heavier side)}$$

$\Sigma F = 0$ and $\Sigma\tau = 0$. Choose the pivot where the most unknown forces act so they drop out. The heavier mass sits closer to the pivot.

Unit 6: Energy and Momentum of Rotating Systems

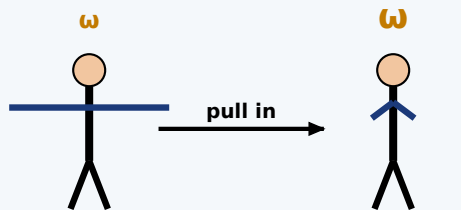
Exam weight: 5–8%

Equation	Best Used When
$K_{\text{rot}} = \frac{1}{2}I\omega^2$	Energy of spinning or rolling objects
$L = I\omega$	Spinning rigid objects; changing I changes ω
$L = mvr \sin\theta$	A point mass moving about a pivot (satellites, impacts on rods)
$\Delta L = \tau\Delta t$	Torque applied over a time
$L_1 = L_2$	No net external torque (skaters, spinning-disc collisions)
Rolling: $v = \omega R$, $K = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$	Rolling down ramps without slipping

Trap: a rolling ball and a sliding block released from the same height do NOT reach the bottom at the same speed. The ball splits its energy between linear and rotational KE, so it moves slower.

Rotation: two results to know

Angular momentum is conserved



arms out

I big, ω small

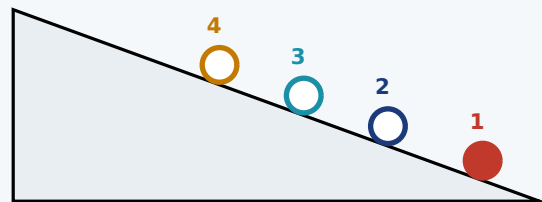
arms in

I small, ω big

No outside torque, so $L = I\omega$ stays constant. Pulling mass inward shrinks I , so ω speeds up. Kinetic energy **rises** because the skater does work pulling in.

Rolling down a ramp

**1 block (slides, no spin) · 2 solid sphere
3 solid disk · 4 hoop (all start from rest)**



Same height, same start: the sliding block wins, then sphere, disk, hoop. The more of the mass sits far from the axis (bigger I), the more energy goes into spinning, so it moves slower. Mass and radius don't matter.

Unit 7: Oscillations

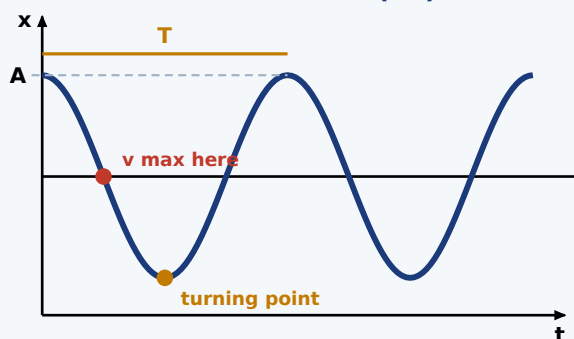
Exam weight: 5–8%

Equation	Best Used When
$T = 1/f$, $\omega = 2\pi f$	Converting period, frequency, and angular frequency
$T_s = 2\pi\sqrt{m/k}$	Mass-spring oscillators; A and g have no effect
$T_p = 2\pi\sqrt{L/g}$	Small-angle pendulums; bob mass and A have no effect
$F_s = -kx$	Finding spring force from stretch or compression
$x = A \cos(\omega t)$	Position at time t if $t = 0$ is at maximum displacement (start at the edge, use cos)
$x = A \sin(\omega t)$	Position at time t if $t = 0$ is at equilibrium (start in the middle, use sin)
$v_{\text{max}} = A\omega = A\sqrt{k/m}$	Maximum speed of a mass-spring oscillator; occurs at equilibrium ($x = 0$)
$E = \frac{1}{2}kA^2$	Total energy or maximum speed of a spring system

Trap: maximum acceleration and restoring force occur at the turning points. At equilibrium in a mass-spring system, net force and acceleration are zero while speed is maximum (a pendulum at the bottom still has centripetal acceleration). Doubling A doubles v_{max} but does not change the period.

Simple harmonic motion at a glance

Position vs. time: $x = A \cos(\omega t)$



A is the amplitude, T the period. Fastest at equilibrium (steepest part of the curve), stopped at the turning points (flat tops). Doubling A does not change T.

Mass on a spring: three snapshots



Restoring force $F_s = -kx$ always points back to $x = 0$. Total energy $E = \frac{1}{2}kA^2$ is constant: all spring energy at the ends, all kinetic at the middle.

Unit 8: Fluids

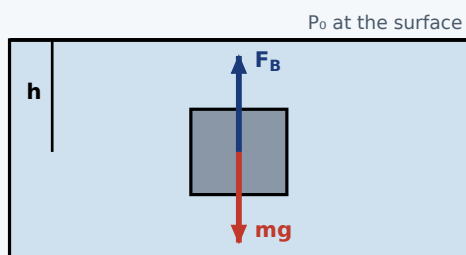
Exam weight: 10-15%

Equation	Best Used When
$\rho = m/V$	Finding density, mass, or volume
$P = F/A$	Pressure from a force on an area
$P = P_0 + \rho gh$	Pressure at depth in a static fluid
$F_B = \rho_{\text{fluid}} V_{\text{displaced}} g$	Floating or submerged objects
$V_{\text{submerged}} / V_{\text{object}} = \rho_{\text{object}} / \rho_{\text{fluid}}$	Floating object at rest: the fraction of it below the surface ($\times 100$ for a percent). Comes from setting $F_B = mg$
$A_1 v_1 = A_2 v_2$	Fluid moving through pipes of different widths
$P + \rho gy + \frac{1}{2}\rho v^2 = \text{constant}$	Pressure, speed, and height changing along a flowing fluid

Trap: buoyant force depends on the displaced volume and fluid density, not the object's mass. An anchor and a wood block of equal volume, fully submerged, feel the same buoyant force.

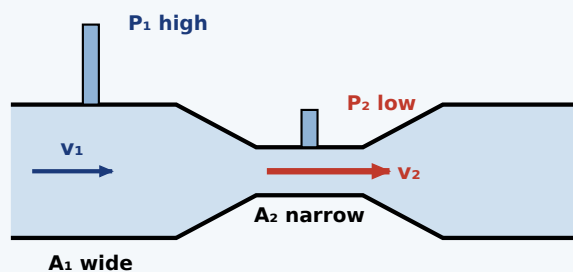
Fluids: two pictures to know

Buoyancy and pressure with depth



$P = P_0 + \rho gh$: pressure grows with depth. The buoyant force equals the weight of the fluid displaced, so it depends on displaced volume and fluid density, not the object's mass.

Flow through a narrowing pipe



Continuity: $A_1 v_1 = A_2 v_2$, so the narrow part flows **faster**. Bernoulli: faster flow means **lower pressure** (the short water column).

Always compare with the official College Board equation sheet for your exam year.